Refractomet Division

UNIVERSAL-CYCLOPS STEEL CORPORATION

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WELDING OF REFRACTORY METALS

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Prepared By

D. J. Seman
F. D. Seaman

UNIVERSAL-CYCLOPS STEEL CORPORATION
REFRACTOMET DIVISION
BRIDGEVILLE, PENNSYLVANIA

FOREWORD

This Quarterly Progress Report covers the work performed under Contract NOw 63-0043-c from 1 October 1963 to 31 December 1963. It is published for technical information only and does not necessarily represent the recommendations, conclusions, or approval of the Navy.

D. J. Seman of the Development Group, Refractomet Division, Universal-Cyclops Steel Corporation was the Engineer in charge. F. D. Seaman was the consultant representing the Astronuclear Department of the Westinghouse Electric Corporation.

Since the nature of this work is of interest to so many fields of endeavor, your comments are solicited as to the potential utilization of the information produced under this contract. In this manner, it is felt that a full realization of the resultant information will be accomplished.

PUBLICATION REVIEW

Reviewed By W. A. McNeish

W. A. McNeish
Assistant Technical Manager
REFRACTOMET DIVISION

Approved By L. M. Bianchi

L. M. Bianchi
Technical Manager
REFRACTOMET DIVISION

ABSTRACT

Contract NOw 63-0043-c

Work accomplished in the quarter is described. Data given shows the effect of InFab atmosphere on bend transition temperature and weld chemistry. Parameters for the multipass welding schedules are presented.

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I. INTRODUCTION

The objectives of this program are to develop production procedures for the joining of refractory metals to form structures for aerospace applications and, using these procedures, to evaluate appropriate equipment. As the first phase of the program a comprehensive industry wide survey was completed. This survey suggested the broad applicability of the versatile inert gas non-consumable electrode fusion welding process.

Accordingly, Phase II of the program was directed toward an establishment of weld parameters for the inert gas non-consumable electrode welding and the evaluation of the effect of restraint using various combinations of parameters. This basic information was used to establish general procedures for autogeneous butt welds (.035" thick), for multipass butt welds (.125" thick) and for manual fillet welds (emphasizing full penetration and contact of the low side contour in the down hand vertical overhead position).

Phase III has been initiated and is aimed at qualifying the above procedures in the InFab environment using bend ductility, penetrant inspection radiography and tensile tests as criteria. Four structural alloys of refractory metals have been investigated. These are: TZM, B-66, 90Ta-10W and W.

II. PHASE II

All of the scheduled tests for Phase II have been completed except for the investigation of wire feed parameters for the Ta-10W alloy. The filler wire is now available and tests have been initiated. The following sections document the results of the final test and describe supplementary tests that have been carried out in some instances.

A. Determination of the Effect of Weld Parameters

A review of bend ductilities of welds produced at speeds ranging from 6 ipm to 30 ipm, with various electrode configuration and with fusion zones ranging from full penetration to burnthrough revealed that the best properties were encountered in the TZM and B-66 alloys when the minimum amperages and speeds were used. At high speeds and/or at high amperages transition temperatures were raised. The effect was not explored on either tungsten, Ta-10W, or tantalum because tungsten was assumed to be similar to TZM and the transition temperature of tantalum and (Ta-10W) is so low that further work to reduce it was not warranted.

Supplementary tests have been initiated to establish the cause of the above phenomena. Tests were rerun on both B-66 and TZM to produce a set of welds with similar fusion zones (approximately .180" i.e. 6T, wide) in the same .035" material from which the first data was gathered.

The same pattern of change in transition temperature was repeated and is illustrated in Figure 1 (i.e. higher speed - higher amperage welds exhibited an undesirable increase in bend transition temperature).

The most significant observation relates to discovery of small transverse cracks in the 12 ipm and 30 ipm welds that have exhibited this speed - transition temperatures effect. If the previous bend tests had been run in the presence of such cracks (and they have, by close examination, been revealed on the undamaged portion of bend specimens) the effect would manifest itself as an apparent increase in the transition temperature. However, further tests are in process to determine if the cracks are the cause of the detrimental effect observed at higher speeds (and to a lesser degree at high amperages at a given speed) or if a more basic phenomena was at work. The cracked material shows

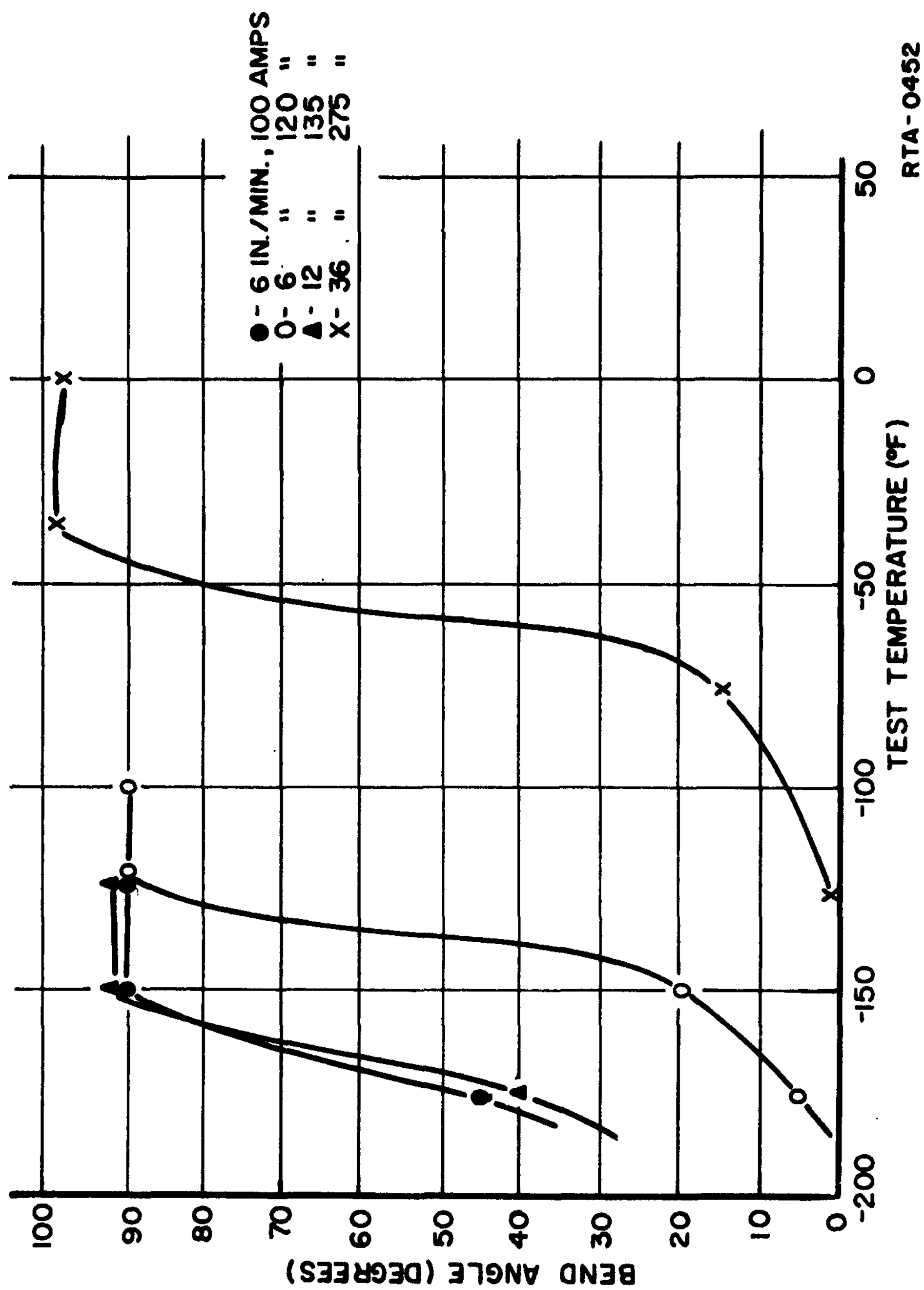

FIGURE I
EFFECT OF WELD SPEED ON BEND TRANSITION TEMPERATURE OF B-66

a pattern of grains extending perpendicular to the fusion isotherm and the cracks lie between the grains. It is not known whether the orientation of grains (and the solidification phenomena associated with it) is the basic cause or if higher speeds and amperages create higher stresses.

Further, a series of tests at the above settings was run on unalloyed molybdenum. Platt[(1)] had reported on improvements in transition temperatures with increasing speed and it was felt that the confirmation of Platt's results would suggest that the converse effect reported above might be related to the more complex alloy systems which characterize TZM and B-66. These tests will be complete in the next period.

B. Restraint Welds

Circular patch tests were run using the soft chill configuration that had been used in the conventional butt welds. Again the variables were adjusted to produce welds with similar fusion zones (.180" wide in .035 material). Again TZM exhibited failures at higher speeds and amperages, the pattern following that observed with regard to transition temperature. Failures were in these tests parallel to the weld centerline (with some transverse cracks) illustrating the different stress pattern between circular and butt welds. The slower speed, lower amperage tests warped which undoubtedly lowered residual stresses. Tungsten cracked under all conditions. Neither B-66 or Ta-10W could be cracked at any speed or amperage combinations.

C. InFab Atmosphere Evaluation

The atmosphere of InFab consists of high purity argon. At present typical impurity readings are in the following ranges: O_2 - 2 to 5 ppm; H_2O - 4 to 10 ppm and N_2 - <20 ppm. The oxygen is read on a Beckman Model 80 continuous oxygen analyzer. The water

is read on a Beckman electrolytic hygrometer. The nitrogen is read either by taking a sample in a pressurized tank and submitting it to an analytic laboratory or by use of a thermal conductivity analyzer. The analyzer in use is not accurate below several hundred parts per million nitrogen.

At the time of the InFab welding evaluation the water vapor analyzer was not installed and the only means of analyzing impurities was the oxygen analyzer, the nitrogen analyzer and the bottled sample technique. To evaluate the effects of impurities in InFab on welding refractory metals, samples were manually welded in copper fixtures. Material used was 0.035" thick. The TZM was welded at 190 amps, the B-66 at 120 amps, the 90Ta-10W at 150 amps and the tungsten at 150 amps. Evaluation of the welds consist of a visual examination, bend transition temperature determination, metallographic examination and chemical analysis. Bend tests were run using MAB 191-M Specification for evaluation of refractory sheet material. The variables included a 4T bend transition temperature, a 1"/min head travel speed and the weld being bent longitudinally with the root in tension.

Bend transition temperature curves are shown in Figures 2 to 6. Figures 2 and 3 show the effect of atmosphere contamination on TZM welds. Figure 2 shows varying oxygen with nitrogen essentially constant. A trend exists showing the BTT to be near room temperature at oxygen levels of 3 to 5, however, raising the oxygen level to 6 to 10 seems to have the effect of producing a BTT of from 180 to 200°F. From these results it seems that a tentative specification for oxygen in InFab with regard to bend transition temperature of TZM should be made at about 5.0 ppm oxygen. Figure 3 shows bend transition curves of TZM while varying both nitrogen and oxygen. The range of DBTT is from approximately 100°F to 275°F. No direct relationship to atmosphere was obtained. The most frequent DBTT is about 200°F.

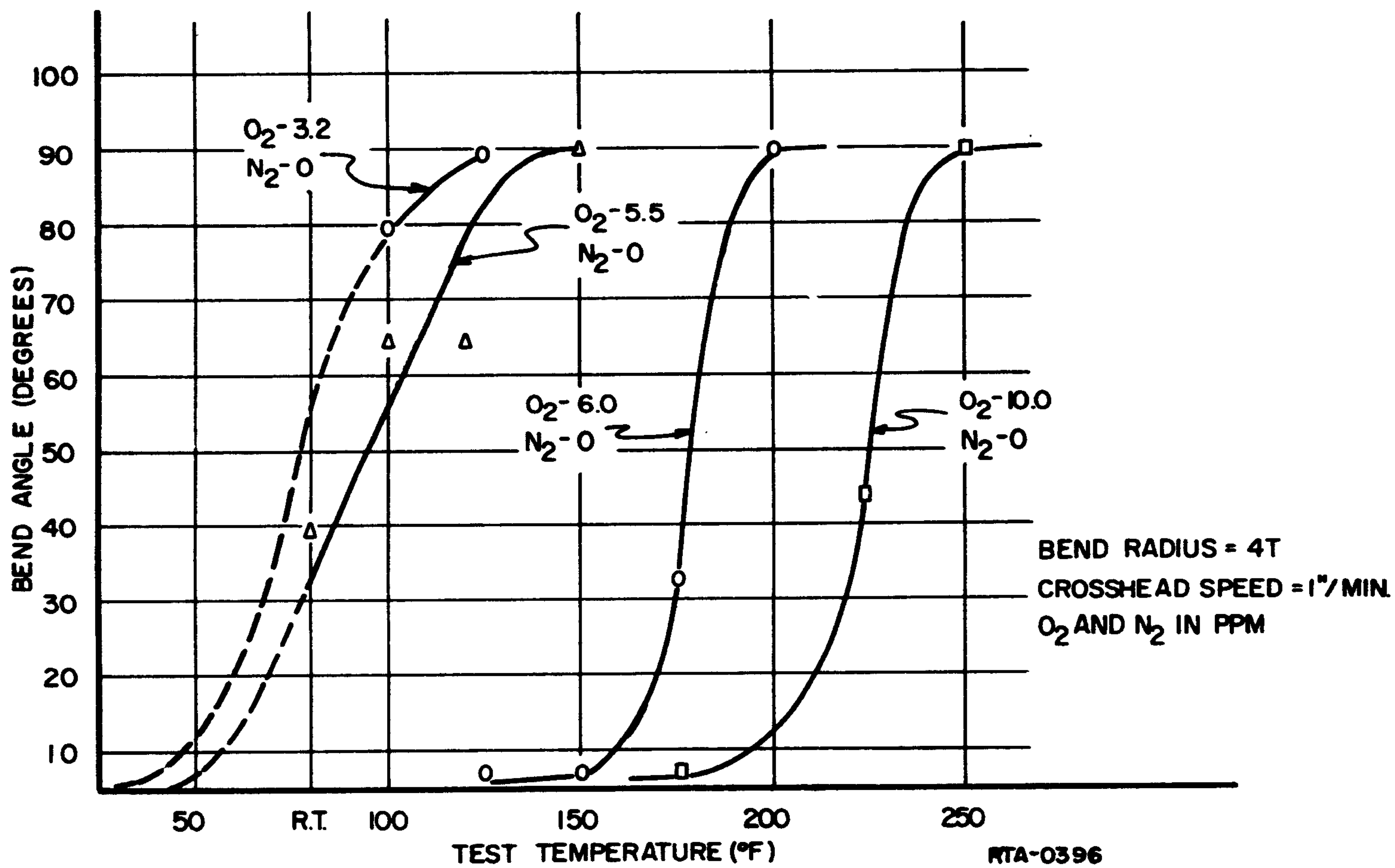

FIGURE 2

EFFECT OF OXYGEN ON BEND TRANSITION TEMPERATURE OF TZM WELDS

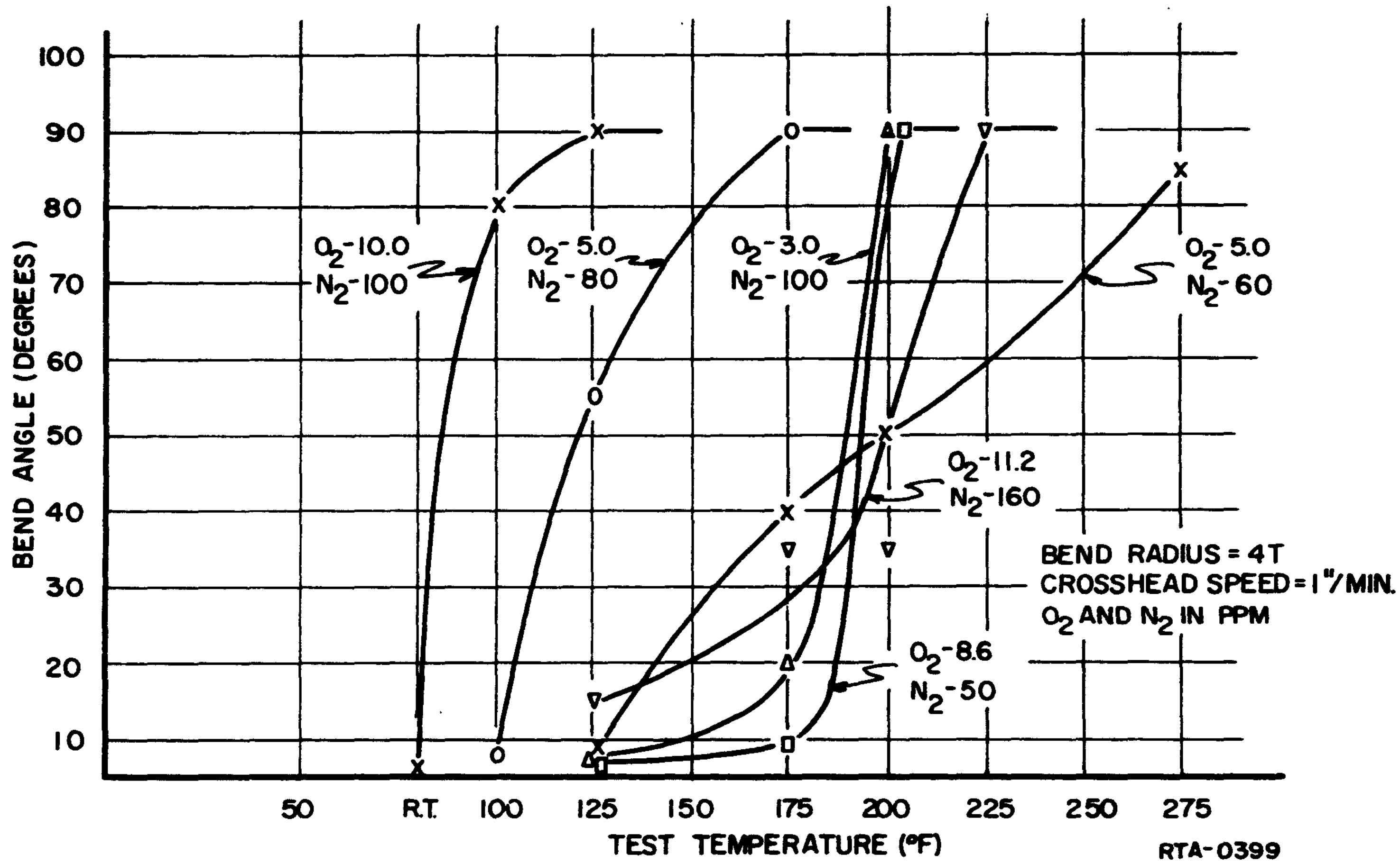

FIGURE 3

EFFECT OF OXYGEN AND NITROGEN ON BEND TRANSITION TEMPERATURE OF TZM WELDS

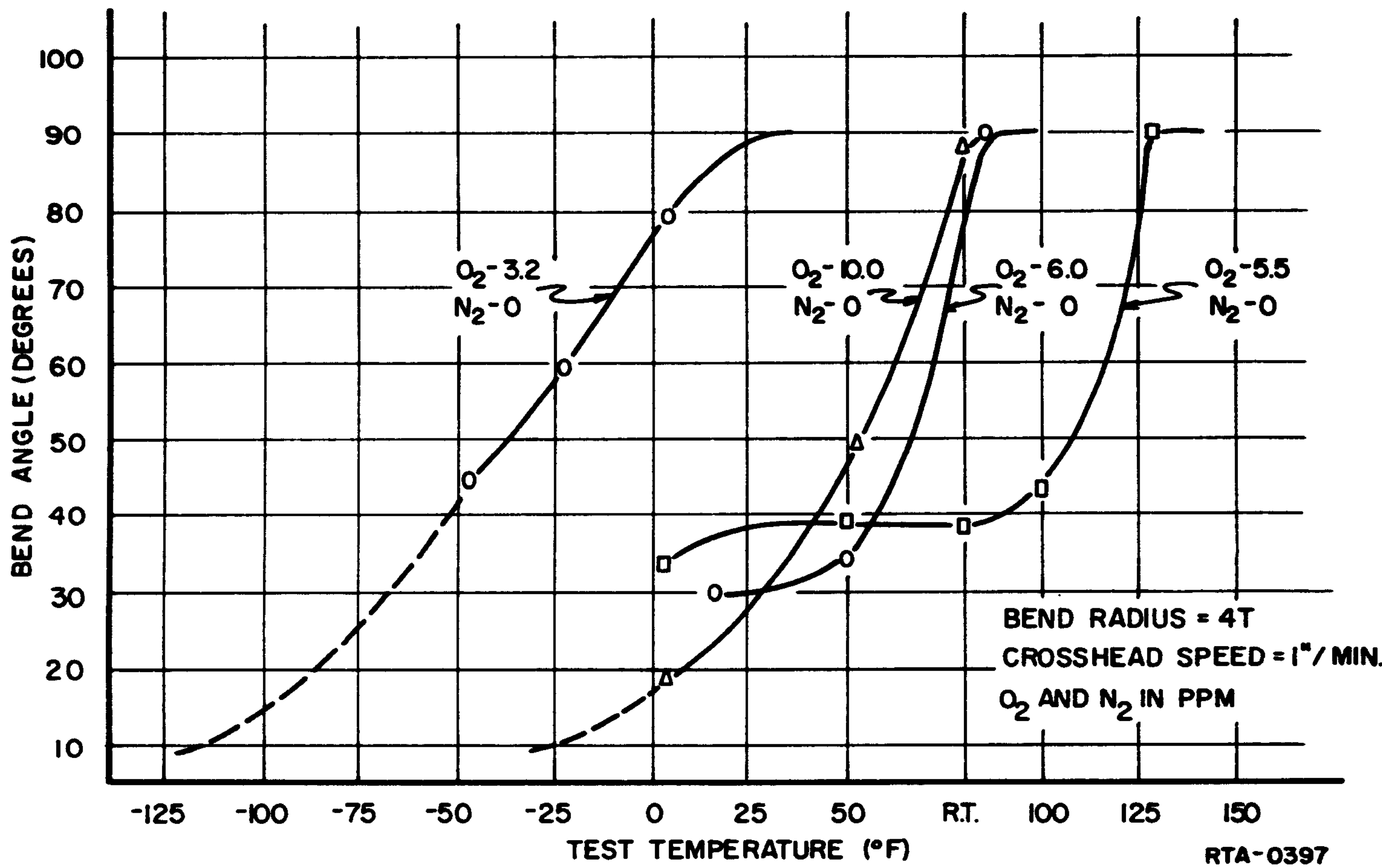

FIGURE 4

EFFECT OF OXYGEN ON BEND TRANSITION TEMPERATURE OF B-66 WELDS

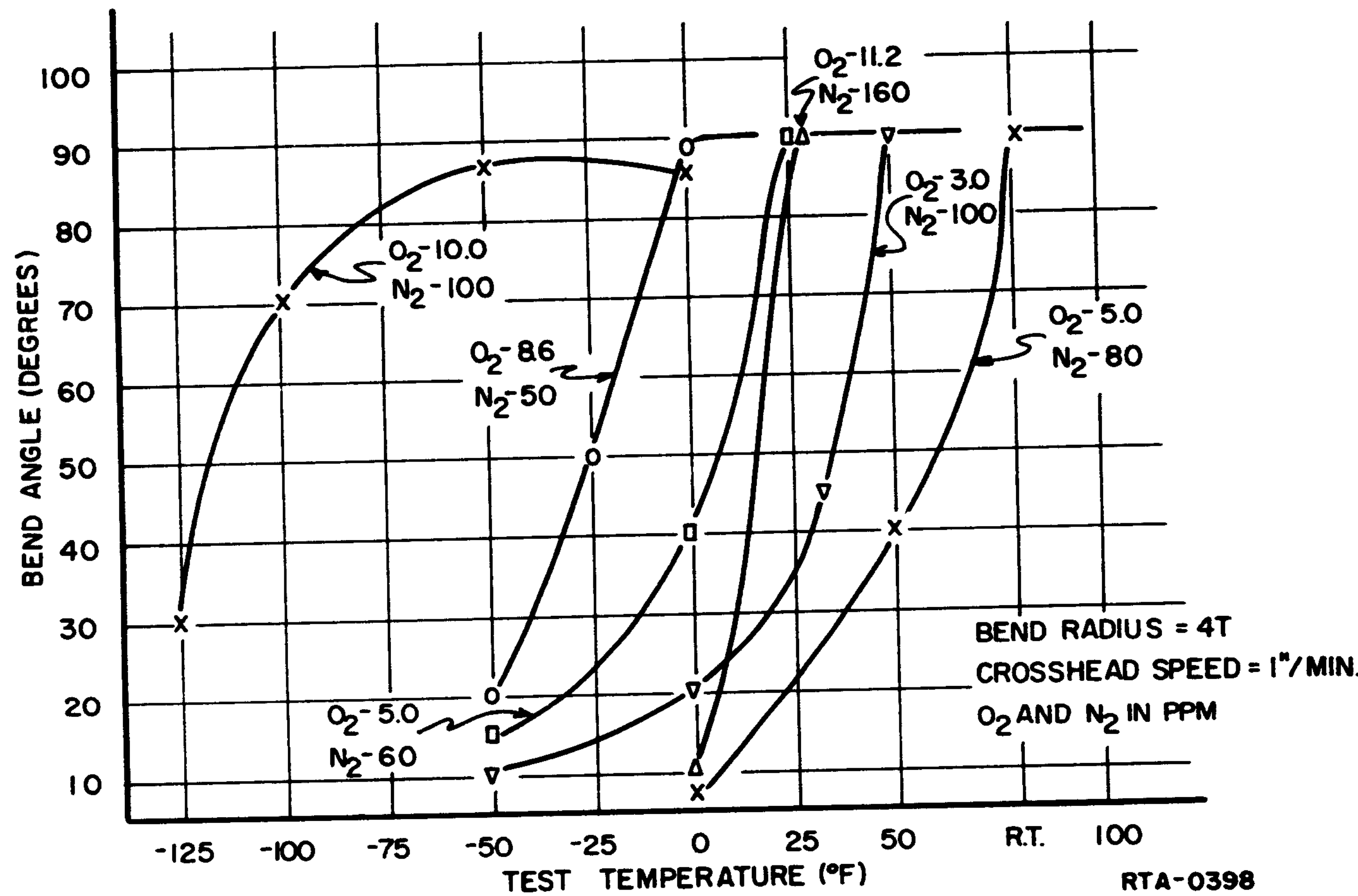

FIGURE 5
EFFECT OF OXYGEN AND NITROGEN ON BEND TRANSITION TEMPERATURE OF B-66 WELDS

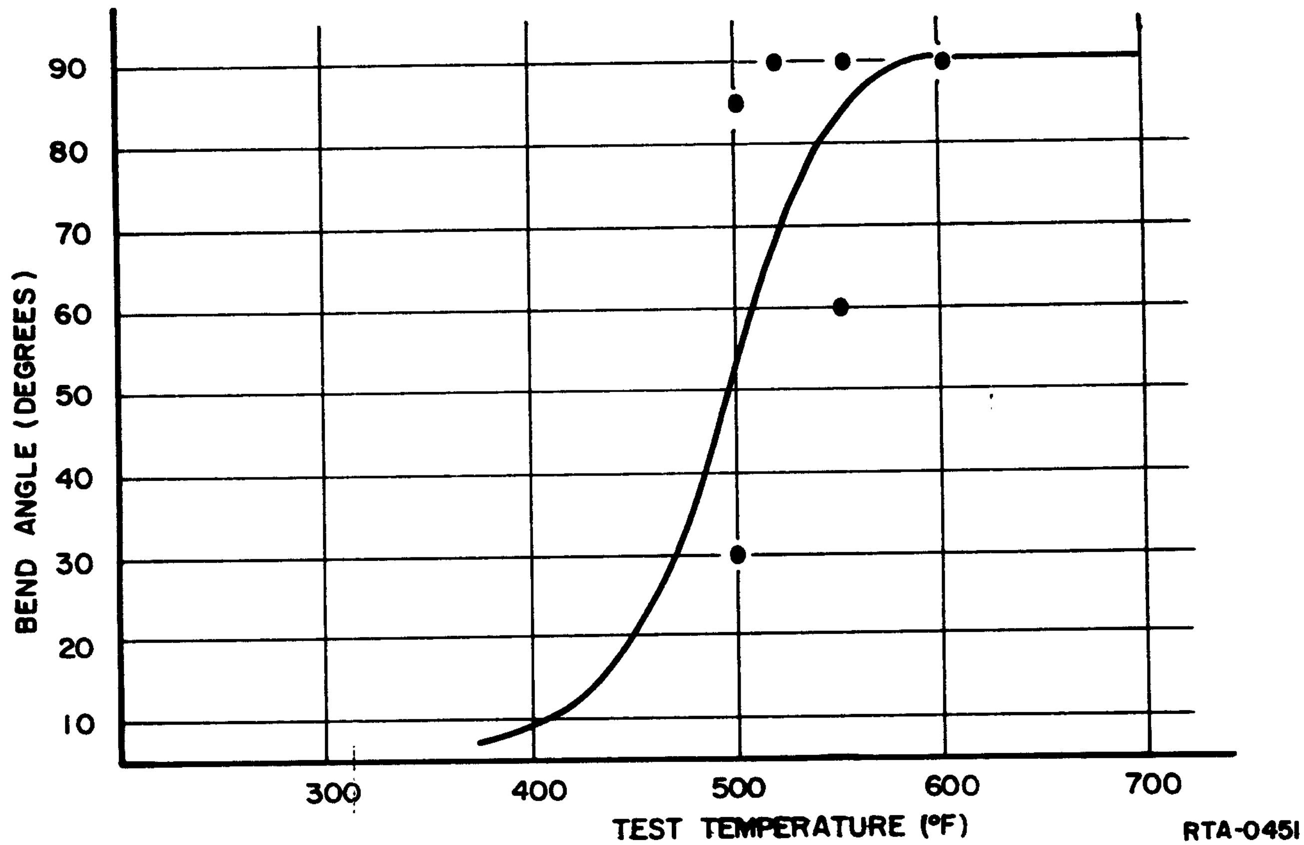

FIGURE 6
BEND TRANSITION TEMPERATURE OF ARC CAST TUNGSTEN WELDS MADE IN INFAB

Figures 4 and 5 show the DBTT for B-66. Figure 4 relates the DBTT with respect to oxygen content in InFab. Again the results did not show a direct correlation to InFab atmosphere, however, the 3.2 oxygen sample did give the lowest transition temperature. When nitrogen was added (Figure 5) to the room again, confusing results were obtained and no direct relationship of bend transition temperature to atmosphere was obtained.

Table I shows the values for the 90Ta-10W. The results are not plotted since no failures were obtained. 4T bend transition temperatures are below -300°F.

The tungsten welds frequently cracked in welding. Also in handling and machining several welds cracked. Final evaluation did not include a complete evaluation of atmosphere, however, a representative bend transition curve was obtained as is shown in Figure 6. The bend transition temperature is approximately 500°F.

In addition to bend transition temperature, chemical analyses (oxygen, nitrogen and hydrogen) of weld bead material was compared with base material chemistry for the various InFab atmospheres. These are shown in Tables II, III and IV, for TZM, B-66 and 90Ta-10W respectively. Chemistries were not taken for the tungsten samples due to insufficient material.

There were no indications of interstitial pickup for the TZM alloy (Table II); weld metal showed no indication of interstitial pickup over the starting material. For B-66 no relationship between O_2 pickup and atmosphere could be observed. For the 90Ta-10W only one case showed substantial oxygen pickup. No reason for this pickup is offered; poorer levels of InFab impurity were investigated which did not show pickup. No measurement of the water vapor present during these welding runs is available. In conclusion, no conclusive detrimental effect of the atmosphere of InFab in the range of atmospheres investigated. This range was approximately 3.2 to 10.0 ppm O_2; 0 to 200 ppm N_2; with water content of about 30 ppm.

TABLE I

BEND DATA OF 90Ta-10W WELDS

InFab Atmosphere (ppm)		Bend Angle (Degrees)	
O_2	N_2 *	-250°F	-300°F
3.2	0	98°	90°
5.0	0	96°	90°
6.0	0	90°	100°
10.0	0	92°	105°
5.0	60	90°	96°
8.6	50	90°	91°
3.0	100	105°	105°
5.5	90	96°	92°
10.0	100	90°	94°
11.8	200	94°	98°

* N_2 as read on thermal conductivity analyzer

TABLE II

CHEMICAL ANALYSIS OF TZM WELD BEAD
VERSUS INFAB ATMOSPHERE PURITY

InFab Analysis (ppm)		Weld Bead Analysis (ppm)		
O_2	N_2*	O_2	H_2	N_2
3.2	0	19	1.2	3
5.0	0	33	1.1	2
6.0	0	22-10	1.3	2
10.0	0	17	1.8	4
5	60	8-10	1.4	5
8.6	50	21	1.0	3
3	100	19	1.3	2
5.5	90	20-30	1.5	7
10	100	17	1.2	7
11.8	200	29	1.0	3
Base Material (Sheet/Ingot)		26/6	<1/3	11/2

* N_2 as read on thermal conductivity analyzer.

TABLE III

CHEMICAL ANALYSIS OF B-66 WELD BEAD
VERSUS INFAB ATMOSPHERE PURITY

InFab Analyses (ppm)		Weld Bead Analysis (ppm)		
O_2	N_2*	O_2	H_2	N_2
3.2	0	105-130	1.3	98
5.0	0	36	2.2	105
6.0	0	37	1.2	113
10.0	0	83-116	1.3	105
5.0	60	32-10	1.3	111
8.6	50	88-60	1.5	117
3	100	70	2.0	120
5.5	90	60-70	-	118
10	100	60	1.6	117
11.8	200	27-50	3.7	112
Base Material (Sheet)		32-22	<1	140

* N_2 as read on thermal conductivity analyzer.

TABLE IV

CHEMICAL ANALYSIS OF 90Ta-10W WELD BEAD
VERSUS INFAB ATMOSPHERE PURITY

InFab Analysis (ppm)		Weld Bead Analysis (ppm)		
O_2	N_2*	O_2	H_2	N_2
3.2	0	21	1.0	7
5.0	0	10-15	1.5	6
6.0	0	25-15	1.0	2
5.0	60	74-66	1.7	10
8.6	50	8	1.0	13
3.0	100	14	1.0	5
10	100	15	1.0	11
11.8	200	10	1.0	3
Base Material (Sheet)		7	<1	16

* N_2 as read on thermal conductivity analyzer.

As a specification for non-critical applications, an atmosphere of about 5 ppm O_2; zero N_2 (as read by presently available instrumentation) and 15 ppm water vapor is set. For highly critical applications an atmosphere of 3 O_2; zero N_2 and 5 water vapor can be achieved and maintained in InFab. As further improvements are made these lower limits undoubtedly will be lowered.

D. Determination of Welding Parameters for Thick Mechanical Butt Welds

Welding techniques are being evaluated on 0.125" thick TZM, B-66, 90Ta-10W and W in order to determine the best parameters for heavy plate welds which included the use of filler wire. The following variables were studied: a. root angle, b. root gap, and c. wire techniques.

a. Root angle including root angles of 60° and 100° were investigated for TZM, B-66 and 90Ta-10W. In all cases the 100° showed excessive "suck up". Upon decreasing the root angle a satisfactory root pass was obtained (with respect to root angle).

b. Root gap - The thick butt welds are being welded at 6"/min. The data on welding speed and bend transition temperature on TZM and B-66 welds given in the previous report indicate that high speed welding should be avoided. Also amperage limitations prevent the investigation of higher speed welds (about 800 - 1000 amps would be necessary). For this reason, problems arose due to the plates tending to pull together i.e. build up stresses at the end of the weld bead. These stresses were such that upsetting of plates occurred at the ends. As a result of these stresses centerline cracking occurred in the more brittle alloys (TZM and tungsten) while in the alloys B-66 and 90Ta-10W, severe warpage occurred. To alleviate this problem several techniques were tried. The first was to provide for a constant root gap of 0.020". This showed no improvement and cracking or warpage was still prevalent. A second attempt was a

0.062" constant gap with wire being fed during the root pass. Again high stresses were built up and centerline cracks developed (only TZM was attempted). Sound welds with minimum warpage were made by tapering the root gap (i.e. at the start of the weld the root gap would be closed while at the end of the weld, a gap of 0.120" would be set). This gives a tapered gap of 0.012"/".

Satisfactory root passes were made with this technique. Three wire feed variations were investigated: wire feed speeds of 6"/min with travel of 6"/min (two wire passes). wire speeds of 12"/min with 6"/min travel and wire speeds of 36"/min with travel speeds of 18"/min. The best results occur with the 12"/min wire speed and 6"/min travel. With the two passes at 6"/min warpage occurred, with the 36"/min wire feed undercutting occurred. One pass at 12"/min produced good weld contour.

III. PHASE III WELD QUALIFICATIONS

Weld qualification consists of three welding procedures. The first is a thin mechanical butt joint. The welds have been made and are now in test. The second qualifying joint is a thick mechanical butt joint. The parameters as discussed in the previous section will be used. The third qualification is a manual inside corner joint. The joint is to be welded from the inside corner and the underbead controlled so that a smooth regular surface is obtained.

References

1. Platt, W. N. "Joining of Refractory Metals" A.I.M.E. Society Conference, Chicago, Illinois, April 12-13, 1962

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